INVESTIGATION OF SOME FACTORS AFFECTING THE HOLE DIGGER PERFORMANCE IN THE SANDY SOIL

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ABSTRACT.

The aim of this research is to study some factors affecting the hole digger performance in the sandy soil. The experiments were conducted in El-Kasasin Research Station in El-Sharkia Governorate. Auger diameters (250 mm) of the developed hole-digger were tested at different auger–speeds (75, 100 and 150 rpm), auger pitches (10, 15 and 20 cm), hole–depths (20, 30 and 40 cm), hole–spacing (5 m) and soil type (sandy) with moisture contents of 15, 22 and 32 % .

The obtained results can be summarized as follow:

The maximum hole productivity rate for sandy soil was 335 hole/h obtained with auger speed of 150 rpm, hole depth 20 cm, auger pitch 20 cm at moisture content 32 %. The penetration resistance of sandy soil at 15 % moisture content increased by 30 and 40.6 % as compared with of sandy soil at moisture content 22 % and 32 %, respectively. The maximum fuel consumption was 0.59 L/h was obtained with auger speed of 150 rpm, hole depth 40 cm, and auger pitch 10 cm. The maximum power requirements 1.91 kW was obtained with auger speed of 150 rpm, hole depth 40 cm, auger pitch 10 cm and moisture content 15 %. The minimum operation cost was 0.04 L.E/hole at auger pitch 15 cm and hole depth 20 cm. Whereas, the maximum operation cost was 0.14 L.E./hole at auger pitch 10 cm and hole depth 40 cm. The operational cost using a hole digger attached to a power tiller decreased by 371 % compared with manual digging.

1. INTRODUCTION.

The greatest two environmental problems in the world are the desertification due to cutting the forest trees for wood and sand movement from desert to cultivated lands. These problems could be solved by cultivation and tree planting.

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Governments take care of tree-planting projects for windbreaks, minimizing of air pollution.

Various agricultural machines were manufactured to save time and effort, and to protect the environment. The hole digger is one of the most important machines used in these objectives. The devolved machine must be not expensive, simple in construction and work in all environmental conditions.

Kapnehko et al. (1976) recommended a hole digger of 30 - 100 cm diameter at penetration speed 1 - 25 cm / s to establish holes for apples. The consumed time was found to be 8, 9 and 12 - 20 s for diameters of 30, 60 and 80 - 100 cm respectively. The hole digger establishes 100 – 150 hole / h for a depth of 60 cm at speed of 180 rpm.

Purtskhvanidze and Keller (1990) tested a hole digger for making on-slopes attachment to a hand-operated tractor 2 kW. They found the tractor saved about 20 – 30 % in power consumption.

Kathirvel, et al. (1990) developed the auger digger as attachment to power tiller of 8 - 10 hp to dig holes for planting seedlings. The unit is capable of digging 35 - 40 hole / h. The machine digs hole of 22.5 cm diameter up to a depth of 45 cm.

El Shal (1993) tested the digger operated with tractor after using a chisel plow with depth of 20 cm. It was found that the productivity of hole digger increased with increasing moisture content of soil and decreasing of the soil depth and resistance.

The maximum productivity of hole digger of 138 hole/h was obtained by using hole depth of 50 cm, moisture content 18 %, hole diameter of 40 cm and sandy soil. Meanwhile, the minimum productivity of hole digger of 66 hole / h was obtained with clay soil by using hole depth of 100 cm, moisture content 11 % and hole diameter of 60 cm. The digging efficiency of hole digger increased with increasing the hole depth, hole diameter, resistance and moisture content of soil. The minimum digging efficiency of 64 % was obtained by using hole diameter of 40 cm, hole depth 50 cm and moisture content 11 % in sandy soil.

Minaei and Arizdeh (2000) designed and developed auger drill for attachment to two wheels tractors for tree-seedlings planting. The machine digs hole of 180 mm diameter up to a depth of 400 mm. Field experiments in showed that the moisture content and soil resistance are two important factors in the bit penetration rate. Drilling rate increased with increasing soil moisture content and decreasing soil penetration resistance. The average drilling rate in sandy clay soil with 25 % moisture content was 1.4 m / min. The unit is capable of digging 100 holes in one hour.

Chaaban et al. (2007) and Khalil (2008) designed and tested a hole digger attached to power tiller. They found that the minimum total digging time with cleaning was 56 s and obtained with auger speed of 200 rpm, hole diameter 15 cm, hole depth 20 cm, and sandy soil. The minimum penetration resistance was 18.1 N/ cm^2 for sandy soil at soil depth of 20 cm. The power requirements increased in loamy soil than sandy loamy and sandy soil by 14.8 and 28.4 % respectively at different parameters. The minimum fuel consumption of 0.37 L/h was obtained with auger speed of 75 rpm, auger diameter 15 cm, hole depth 20 cm, hole spacing 1 m and sandy soil. The minimum power requirements of 1.18 kW was obtained with auger speed of 75 rpm, hole diameter 15 cm, hole depth 20 cm, hole spacing 1 m and sandy soil. The minimum average range of operation costs with and without cleaning were 0.12 and 0.016 L.E/hole respectively for sandy soil at auger diameter 15 cm, hole depth 20 cm and hole spacing 1 m.

Kathirvel et al. (1990) indicated that the cost of digging holes and the time consumed by power tiller hole digger was minimum as compared to the manual digging by 6 % for making 100 holes. Also, they found the cost of hole digging decreased by 179 % as compared to the digger operated with tractor.

Yehia et al. (2009) found that the maximum hole productivity of 324 hole/h was obtained with auger speed of 150 rpm, hole diameter 15 cm, hole depth 20 cm, auger pitch 20 cm at moisture content 26%. The maximum fuel consumption was 0.69 L/h was obtained with auger speed of 150 rpm, hole diameter 25 cm, hole depth 40 cm, and auger pitch 10 cm. The maximum power requirements was 2.72 kW was obtained with auger speed of 150 rpm, hole diameter 25 cm, hole depth 40 cm, auger pitch 10 cm and moisture content 18 %. The operation costs by using a hole digger attached to a power tiller decreased by about 500 - 950 % compared with manual digging.

The objective of the present work is to study the affecting factors on performance of a developed hole digger **(which designed by Chaaban et al., 2007 and Khalil, 2008)** such as auger pitch, speed and moisture content of sandy soil in order to improve the performance of this implement.

2. MATERIALS AND METHODS.

2.1. Experimental site:

The experiments were carried out during the years of 2011 and 2012 in El-Kasasin Research Station, at moisture contents of 15, 22 and 32 %. The mechanical analysis of the experimental soil was classified as sandy soil as shown in **Table 1**.

Table 1: Mechanical analysis of the experimental soil .

Soil Depth	Sand, %.	Silt, %.	Clay, %.	Soil Texture class
0 – 40 cm	93	6	1	Sandy

(1) The developed hole-digger: The developed hole digger (which designed by **Chaaban et al., 2007 and Khalil, 2008**) is shown in **fig. 1(a,b).** The developed hole-digger consists of the following parts :

(a) Frame: The frame was made of square-section steel tubing with dimensions of 80 X 80 mm, with thickness of 3 mm. The total length of frame is 375 mm and width is 355 mm. The height of frame from soil level is 525 mm.

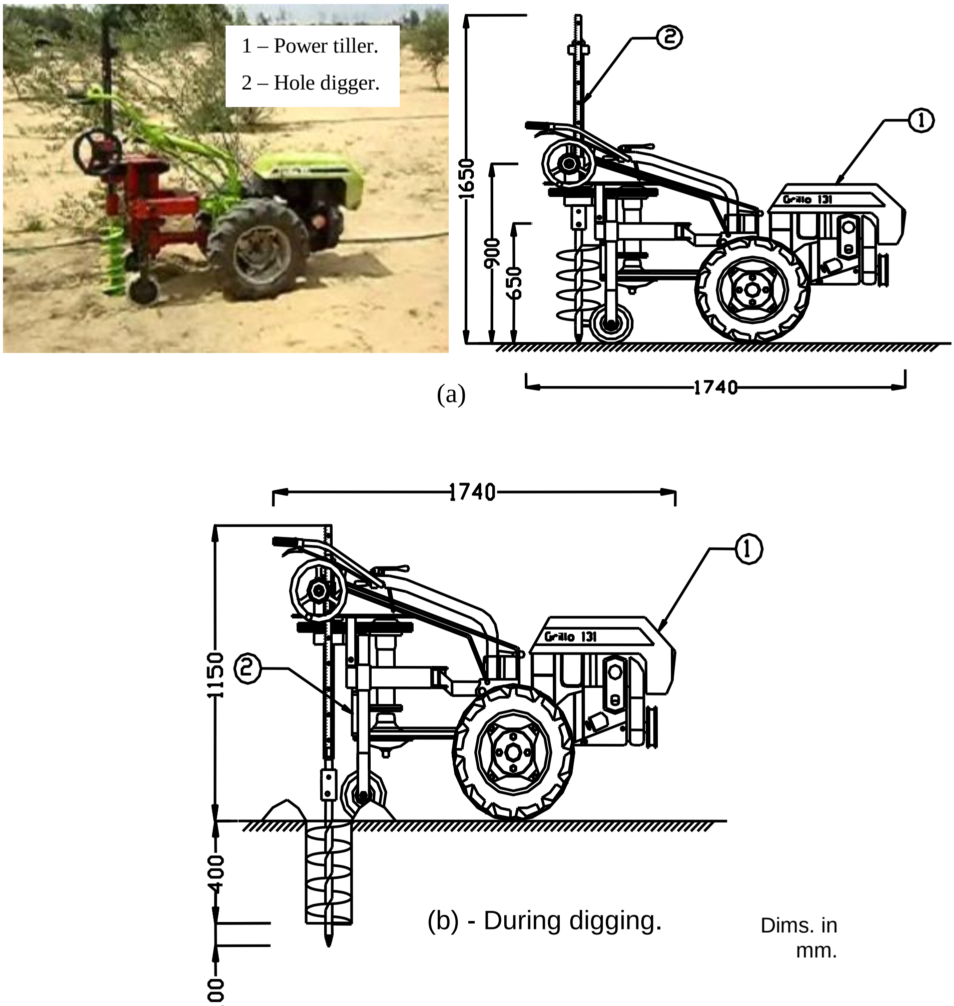

Fig. 1: View of the developed hole digger attached to a power tiller

(b) Two stands with ground wheels: Two stands and two ground wheels carry the frame and all parts of the hole digger. Each stand was made of square-pipe steel of 50 X 50 mm, with thickness of 3 mm. The total length of stand is 550 mm. The distance between two stands is 400 mm. Two plastic ground-wheels were attached with the bottom of stands by two pins. The diameter of each ground wheel is 200 mm and the width is 45 mm.

(c) Hexagonal steel-shaft: The augers were fitted with the bottom of hexagonal steel-shaft by steel ring and pin. The power is transmitted to the hexagonal shaft by two gears. The hexagonal shaft was fitted with second gear with hexagonal ring. The hexagonal shaft is 42 mm diameter and 800 mm total length.

(d) Depth-gauge (adjusting) mechanism: The mechanism consists of three parts: (a) Gear with 21 teeth, 66 mm diameter and 33 mm thickness, (b) The rack with length of 870 mm, width of 32 mm and number of teeth 83 and (c) Manual wheel with 250 mm diameter rotated by welded handle with length of 125 mm.

(e) Auger (Fig. 2): Auger with diameter 250 mm was constructed and tested. The total length of auger was 625 mm. The auger pitch "p_t" affects the penetration and cutting into soil. Too small or too large pitch will make it more difficult to penetrate soil. In fact, the penetration angle "α" can be calculated and is shown in **table 2** as fallows:

$$\alpha = \tan^{-1}\left(\frac{p_t}{2\,d}\right)$$

Where "α" increased from the outer edge of auger helix to the inside of its flute. Moreover the optimum penetration angle depends on soil type and compaction.

Table 2: The relation between auger diameter, auger pitch and. penetration angle of auger

Auger diameter, cm.	25		
Auger pitch, cm.	10	15	20
Penetration angle.	11^o	17^o	22^o

The steel type of the auger knife was named "Bohler K100 or DIN 1.2080 X210Cr12". The chemical composition of steel knife **(Bohler company – 2006)** is shown in **table 3**.

Table 3: The chemical composition of steel knife of auger**.**

The elements, %.					
C	Si	Mn	Cr	Ni	W
1.98	0.19	0.32	11.84	0.18	0.05

C: carbon **Si**: Silicon **Mn:** Manganese **Cr**: Coram **Ni:** Nickel **W:** Tungsten

The hardness of the knife steel is up to 63 – 65 HRC HRC (Hardness Rockwell Scale) at temperature of 940 to 970 C ^{o}.

(2) Power tiller: Power transmissions from power tiller auger of hole digger was shown in **fig. 3**. The specifications of the power tiller were as follow:

Model: Grillo 131, Italian made, Engine power: 10 kW (13.6 hp), speed: 5 forward speeds (1.2 – 4.2 km / h) and 2 reverse speeds (0.8 – 1.7 km/h) and power take-off (PTO) speed: 1028 rpm.

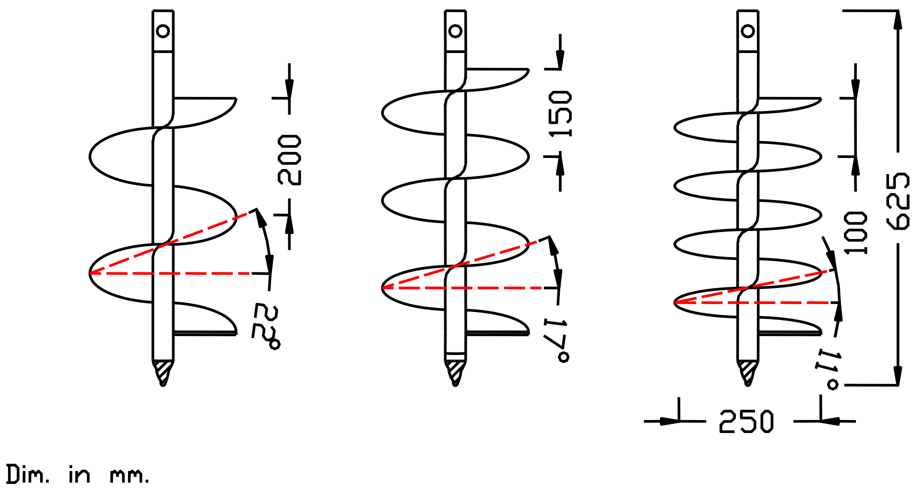

Fig. 2: The Auger of different pitches 100, 150 and 200 mm.

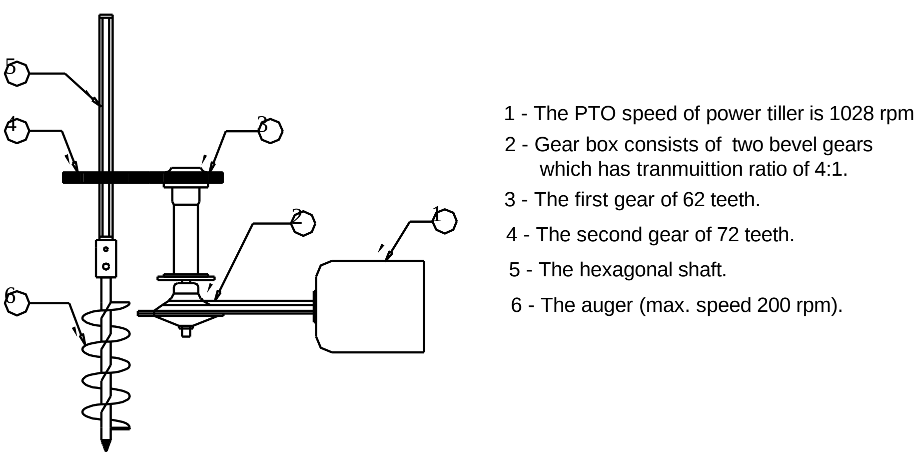

Fig. 3: Power transmissions from power tiller to auger of hole digger

2.2. Instrumentations:

(a) Pentrometer resistance measurements: Soil penetration can be measured by a cone penetrometer. A cone penetrometer was specified by A S A E S 3I3 – 1 as cited by Agricultural Engineers as 30 circular stainless steel cone with driving shaft. The cone index has been defined as the force per unit depth of penetration according to the following equation:

$$R = F/A \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots N/cm^2$$

Where: R= Specific soil penetration, F= Required force, and A= Projected area of penetrometer. The push type penetrometer was used to determine penetrometer resistance of the soil profile before digging operations.

(b) Speedometer: A speedometer was used to measure the auger speed with the three ranges available: 1st range 5 -50 m/min. (50 – 500 rpm) direct reading. 2nd range 50 – 500 m/min. (500 – 5000 rpm) scale value rpm × 10. 3rd range 500 – 5000 m/min. (5000 – 50000 rpm) scale value rpm × 100.

2.3. Measurements:

(1) Fuel consumption and power requirement: Fuel consumption was determined by measuring the required fuel to refill the fuel tank after the treatment period. Consumed energy per feddan was calculated through measuring fuel consumption for each of treatment operating speed. The power tiller was instrumented to measure run time and fuel consumption. The consumed energy was calculated by using the following formula:

$$\mathbf{P} = \mathbf{3.23}\, \boldsymbol{F_c}$$ cited by **(Hunt, 1983)**.

Where: P=Power requirements (kW), $\boldsymbol{F_c}$ = The fuel consumption (L/h.).

(2) Digging efficiency: The percentage volume of the soil resulted from the digging was estimated by measuring the height (H_1) and the width (L) of heaped soil round the hole **(Fig. 4)**. Where: $L = R_1 - R_0$ cm. All measurements were carried out at three angular speeds of 75, 100 and 150 rpm, auger-diameter of 25 cm and three hole-depths of 20, 30 and 40 cm. To achieve the highest digging efficiency and shape uniformity of the hole, R_1 had to be $\leq$ 3-3.5 R_0 **(Scripnic, 1968).** Moreover, volume of the soil resulted from digging must be equal to hole volume multiplied by the swelling factor of soil.

$$H_1 = \frac{K_a\, H_0\, (R_0)^2}{R_g\, (R_1 - R_0)}$$

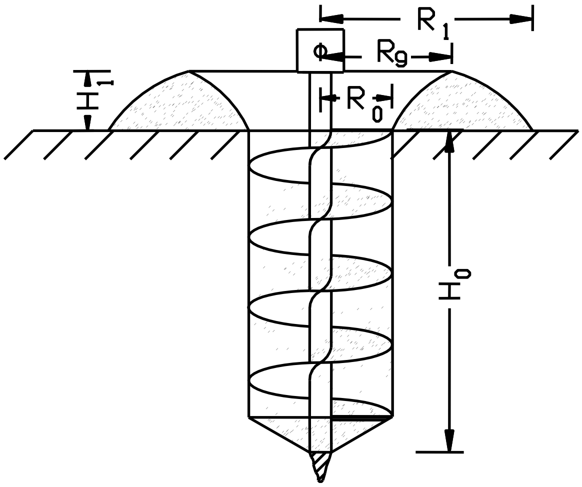

Fig. 4: Hole dimensions.

Where: R_0: Radius of the hole, cm, R_1: Radius from the end of the accumulated soil., cm, R_g: Radius from the center to the middle of the accumulated soil, cm, H_1: The height of the soil resulting from digging, cm, H_0: Hole depth, cm, and K_a: swelling factor. Swelling factor (K_a) was calculated for sand soil (1.58).

The digging efficiency was calculated by using the following formula:

$$\eta_d = \frac{V_{res.}}{V_{total}} \times 100 \quad \text{..........\%}$$

Where: η_d = Efficiency of the digging, $V_{res.}$ = Volume of the soil resulted from the digging (soil outside the hole), $V_{total.}$ = Volume of the total soil inside and outside the hole.

(3) Cost: The operation costs of the designed hole digger attached to a power tiller calculated according to equation of **Awady, 1978** in the following form: $C = \frac{P}{h}(\frac{1}{a} + \frac{i}{2} + t + r) + (1.2\ \ w.s.f) + \frac{m}{144}$

Where: C = Hourly cost, P = Price of the machine and power tiller, h = Yearly working hours, a = Life expectancy of the machine in years, i = Interest rate/year, t = Taxes rate, r = Repairs and maintenance ratio, w = Power of the machine kW, s = Specific fuel consumption L/kW.h , f = Fuel price L.E./L , m = Monthly wage, 1.2 = Factor accounting for ratio of rated power and lubrications, 144 = The monthly average working hours.

Table 4: The constants used in Awady equation:

P, L.E. *	h, h/year	a, year	i, %	t, %	r, %	w, kW	s, L/kW.h **	f, L.E/L	m, L.E/month
21000	1000	10	7	5	6	10	0.36	0.6	1000

* P = price of a hole digger + power tiller = 3000 + 18000

** Measured specific fuel consumption.

Cost of digging one holes = $\frac{Hourly\ \ cost,\ \ LE}{Holes\ \ production\ \ per\ \ hour}$.….LE/hole

3. RESULTS AND DISCUSSION.

3.1. Penetration resistance.

Fig. 5 shows the penetration resistance for sandy soil at different moisture content and different soil depths. The maximum penetration resistance was 41.5 N/ cm^2 at 15 % moisture content and soil depth 40 cm. Whereas, the minimum penetration resistance was 16.2 N/ cm^2 at 32 % moisture content and soil depth 20 cm. The increasing of penetration resistance by increasing the soil depth and decreased of moisture content.

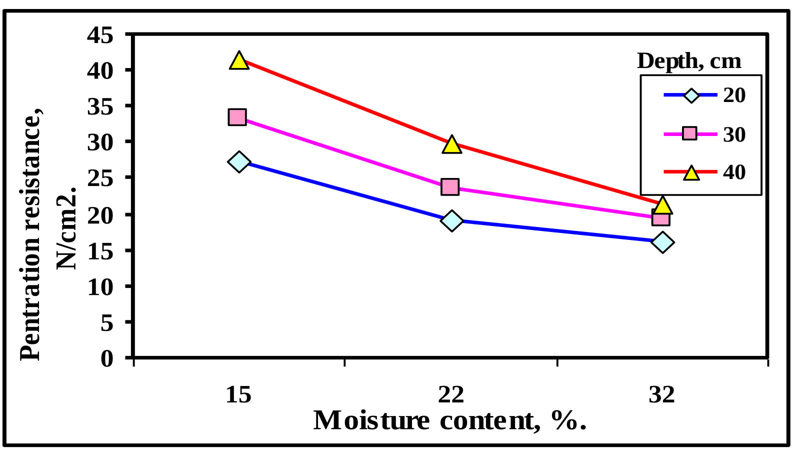

Fig. 5: Penetration resistance for sandy soil at different moisture-contents and soil-depths.

3.2. Effect of auger speed, auger pitch (penetration angle), moisture content and hole depth on hole-digging production rate for hole diameter 25 cm and sandy soil.

Fig. 6 shows the effect of auger speed, auger pitch, moisture content and hole depth on hole-digging production rate for sandy soil. The maximum hole productivity of 335 hole/h was obtained with auger speed of 150 rpm, hole depth 20 cm, auger pitch 20 cm at moisture content 32 %. Whereas, the minimum hole productivity of 100 hole/h was obtained with auger speed of 75 rpm, hole depth 40 cm and auger pitch 10 cm at moisture content 15 %. The hole digging productivity increased with increasing auger speed, auger pitch and moisture content, decreased by increasing hole depth.

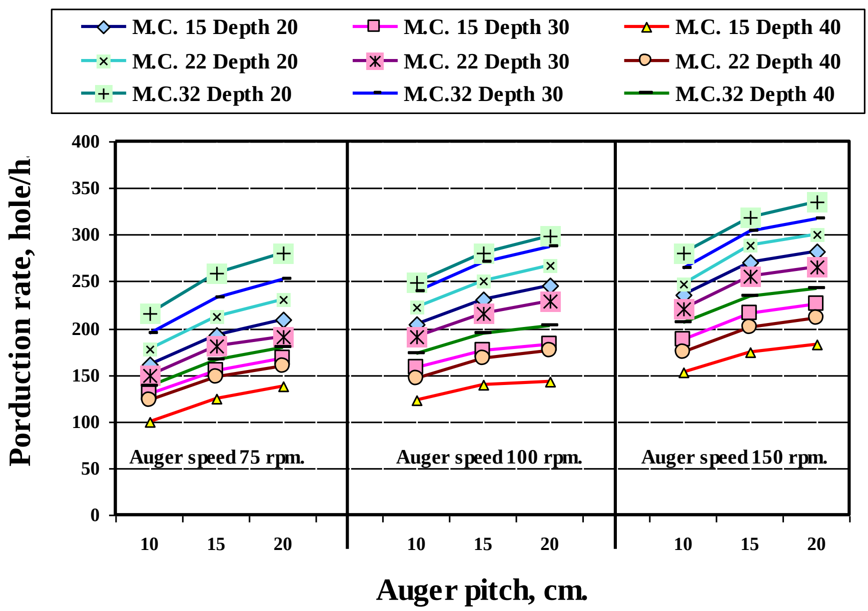

Fig. 6: Effect of auger speed, auger pitch, moisture content (%) and hole depth on hole-digging production rate for sandy soil.

3.3. The effect of different working parameters on digging efficiency % .

Fig. 7 shows the effect of auger speed, auger pitch, moisture content and hole depth on digging efficiency for sandy soil. The digging efficiency increased by increasing auger speed, hole depth and moisture content of soil. The maximum digging efficiency was 95 % at auger speed 150 rpm, auger pitch 20 cm, hole depth 40 cm and moisture content 32 %.

Whereas, the minimum digging efficiency was 39 % at auger speed 75 rpm, auger pitch 10 cm, hole depth 20 cm and moisture content 15 %.
The increasing of digging efficiency is due to increasing the mass of digging soil. The increasing of digging efficiency by increasing soil moisture-content is due to decreasing soil stability.

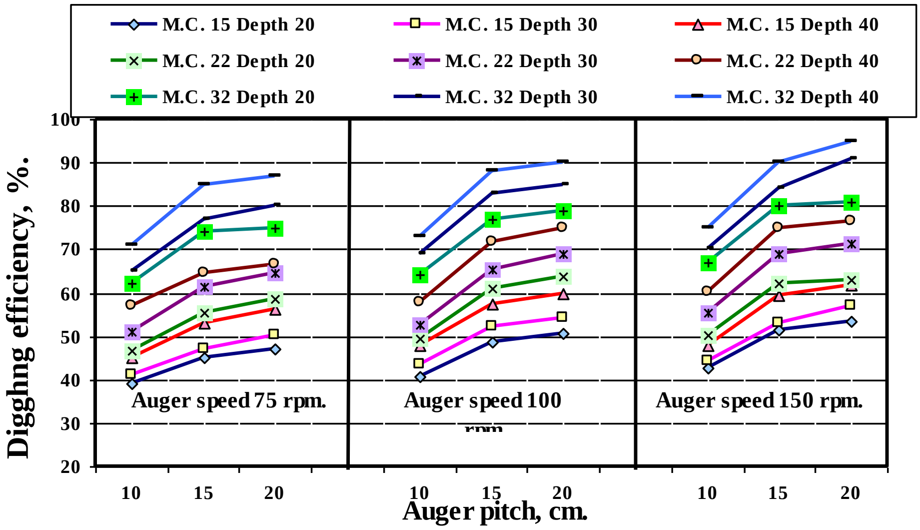

Fig. 7: Effect of auger speed, auger pitch, moisture content (%) and hole depth on digging efficiency for sandy soil.

3.4. The effect of different working parameters on fuel consumption.

Fig. 8 shows the effect of auger speed, auger pitch, moisture content and hole depth on fuel consumption. The maximum fuel consumption was 0.59 L/h was obtained with auger speed of 150 rpm, hole depth 40 cm, auger pitch 10 cm and moisture content 15 %. Whereas, the minimum fuel consumption of 0.27 L/h was obtained with auger speed of 75 rpm, hole depth 20 cm, auger pitch 20 cm and moisture content 32%. The fuel consumption of the developed hole-digger increased with increasing auger speed, hole depth and soil resistance. The increasing of fuel consumption by decreasing soil moisture content and auger pitch is due to increasing penetration soil-resistance.

3.5. The effect of different working parameters on power requirements

Fig. 9 shows the effect of auger speed, auger pitch, moisture content and hole depth on power requirements. The maximum power requirements was 1.91 kW was obtained with auger speed of 150 rpm, hole depth 40 cm, auger pitch 10 cm and moisture content 15 %. Meanwhile the minimum power requirements of 0.87 kW was obtained with auger speed of 75 rpm, hole, hole depth 20 cm, auger pitch 20 cm and moisture content 32 %. The power requirements of the developed hole-digger increased with increasing auger speed, hole depth and soil resistance. The increasing of power requirement by decreasing soil moisture content and auger pitch is due to increasing penetration soil-resistance.

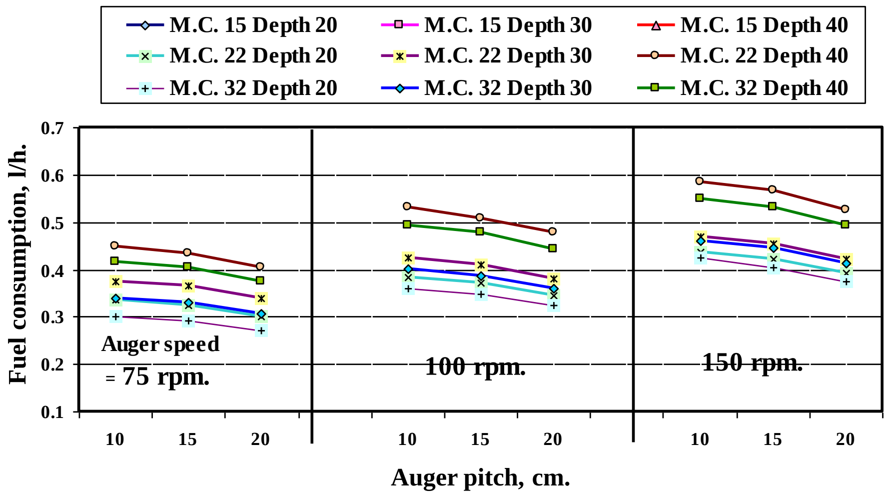

Fig. 8: Effect of auger speed, auger pitch, moisture content (%) and hole depth on fuel consumption of digging the sandy soil.

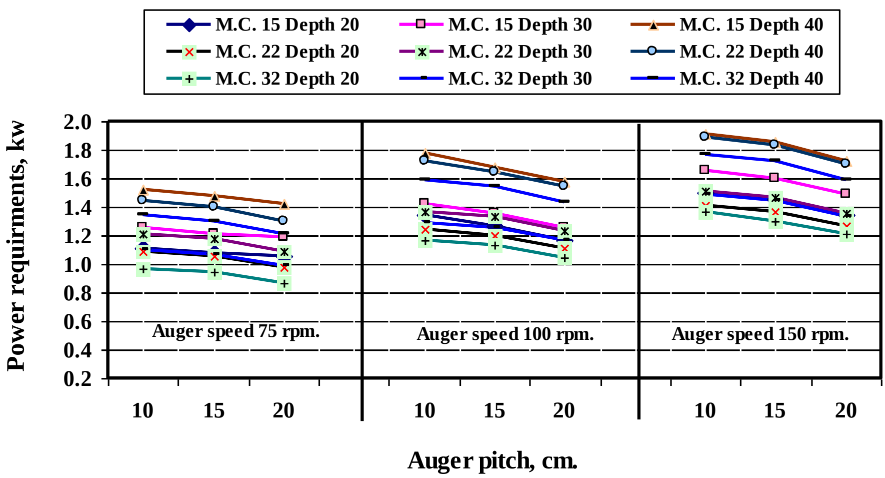

Fig. 9: Effect of auger speed, auger pitch, moisture content and hole depth on power requirements of digging the sandy soil.

3.6. Cost of using the modified hole digger.

Table 5 shows the effect of auger pitch, hole depth, and soil moisture-content on operation cost of hole digger speed of 150 rpm in sandy soil. The minimum operation cost was 0.04 L.E/hole at auger pitch 15 cm, hole depth 20 cm and soil moisture-content 32 %. Whereas, the maximum operation cost was 0.14 L.E./hole at auger pitch 10 cm, hole depth 40 cm and soil moisture-content 15 %. The operation cost increased by increasing hole depth and soil penetration resistance at different parameters. **Table 6** shows the hole productivity and operation cost for one hole by using manual digging at auger pitch of 15 cm, moisture content of 32 % and different hole-depths and auger- pitch. diameters. The operation cost by using a hole digger attached to a power tiller decreased by about 371 % compared with manual digging.

Table 5: Cost of using a developed hole-digger at auger speed of 150 rpm and different soil moisture-content, hole-depths and auger-pitch.

Moisture content of soil, %.	**Hole depth, cm.**	**Cost, L.E./hole. Auger diameter,25 cm.**		
		Auger pitch, 10 cm.	**Auger pitch, 15 cm.**	**Auger pitch, 20 cm.**
	20	0.07	0.06	0.05
	30	0.08	0.07	0.07
15	40	0.14	0.12	0.11
	20	0.05	0.05	0.05
	30	0.07	0.06	0.05
22	40	0.1	0.09	0.08
	20	0.05	0.04	0.04
	30	0.06	0.05	0.05
32	40	0.08	0.07	0.06

Table 6 : Productivity and operation cost for one hole by using manual digging at auger diameter 25 cm, depth of 40 cm at moisture content of 15 %

	Auger diameter, 25 cm.	
Hole depth	Hole /day.	Cost, LE./hole
20	90	0.30
30	60	0.50
40	45	0.66

CONCLUSIONS.

The results can be summarized as follows:

The penetration resistance of sandy soil at 15 % moisture content increased by 30 and 40.6 % as compared with of sandy soil at moisture content 22 % and 32 % respectively. The maximum hole productivity rate for sandy soil was 335 hole/h obtained with auger speed of 150 rpm, hole depth 20 cm, auger pitch 20 cm at moisture content 32%. Whereas, the minimum hole productivity of 100 hole/h was obtained with auger speed of 75 rpm, hole depth 40 cm and auger pitch 10 cm at moisture content 15 %. The maximum fuel consumption was 0.59 L/h was obtained with auger speed of 150 rpm, hole depth 40 cm, and auger pitch 10 cm. The maximum power requirements 1.91 kW was obtained with auger speed of 150 rpm, hole depth 40 cm, auger pitch 10 cm and moisture content 15 %.

- The maximum operation cost was 0.14 L.E./hole at auger pitch 10 cm and hole depth 40 cm. The operation costs by using a hole digger attached to a power tiller decreased by about 371 % compared with manual digging .

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الملخص العربى

دراسة بعض العوامل المؤثرة على أداء حفار جور فى الأراضى الرملية

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يهدف هذا البحث إلى دراسة بعض العوامل المؤثرة على أداء حفار جور المطور المعلق على جرار صغير ذو عجلتين لغرس شتلات الفاكهة وشتلات مصدات الرياح وشتلات تشجير الطرق مثل خطوة وزاوية اختراق وسرعة وعمق حفر البريمة ونسبة رطوبة التربة .

ملخص النتائج التى تم الحصول عليها كالتالى:

- أعلى إنتاجية لحفار الجور كانت ٣٣٥ حفرة / ساعة عند ظروف تشغيل ١٥٠ لفة / دقيقة وعمق الحفر ٢٠ سم وخطوة البريمة ٢٠ سم وذلك عند محتوى رطوبى للتربة ٣٢ %.
- مقاومة التربة المستخدمة عند محتوى رطوبى ١٥ % تزيد بنسبة ٣٠ و ٦.٤٠ % مقارنة بالتربة المستخدمة عند محتوى رطوبى ٢٢ % و ٣٢ % على الترتيب.
- كانت أكبر كمية وقود مستهلكة ٠.٥٩ لتر/ساعة وذلك عند ظروف تشغيل ١٥٠ لفة / دقيقة وعمق الحفر ٤٠ سم و خطوة البريمة ١٠ سم وذلك عند محتوى رطوبى للتربة ١٥ %.
- كانت أعلى قدرة مطلوبة فى عمليات التشغيل للأرض الرملية ١.٩١ كيلووات وذلك عند ظروف تشغيل ١٥٠ لفة / دقيقة وعمق الحفر ٤٠ سم وخطوة البريمة ١٠ سم وذلك عند محتوى رطوبى للتربة ١٥ %.
- أدنى تكاليف كانت ٠.٠٤ جنية / جورة وذلك عند خطوة بريمة ١٥ سم، وعمق حفر ٢٠ سم، ونسبة رطوبة تربة ٣٢ %. بينما كان أقصى تكاليف ٠.١٤ جنية / جورة عند خطوة بريمة ١٠ سم، وعمق حفر ٤٠ سم، ونسبة رطوبة تربة ١٥ %. و استخدام حفار الجور المعلق على جرار صغير ذى عجلتين يوفر التكاليف بنسبة حوالى ٣٧١ % مقارنة بعمليات الحفر اليدوية.

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(١) باحث ، (٢) باحث أول ، معهد بحوث الهندسة الزراعية.